Coupling of Ferromagnets and Anti-Ferromagnets

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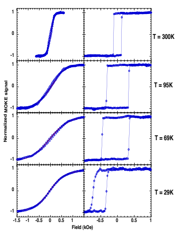
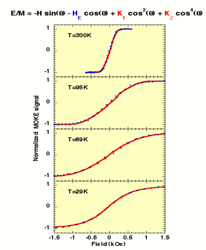
Motivation: The microscopic origin of exchange bias, the phenomenon by which the hysteresis loop of a ferromagnet is shifted from the zero field position, is not well understood even though it has already found technological applications.

We have investigated a Co film deposited on a single crystal of FeF_2.

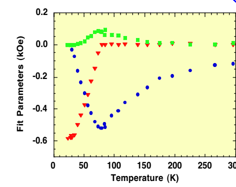
The novelty of our approach is that it enables us to cool the sample in a field and then to rotate it. This allows us measure exchange biased hard axis loops.



The advantage of the hard axis loops is that they can be fit analytically and yield quantitative values for the anisotropies. (Fits, shown by the red lines, yield K_1 and K_2.)



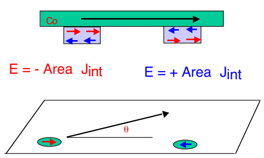
Temperature dependence of the bias and anisotropies.



$E/M = -H \sin(\theta) - H_E \cos(\theta) + K_1 \cos^2(\theta) + K_2 \cos^4(\theta)$

Why are the anisotropies and bias correlated above and below the Neel temperature?

Simple schematic of coupling at a F/AF interface



We assume an interface energy/area

$$E_{ex} = -J_{Int} \cos(\theta)$$

even above T_N.

This implies AF order at the interface at all temperatures.

The probability f that an AF 'domain' is aligned or anti-aligned with the F is:

$$f^{\pm} = \exp\{\pm x\}/[\exp\{+x\} + \exp\{-x\}]$$

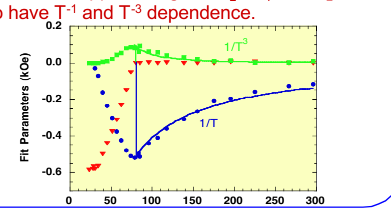
$$x = [A\, J_{Int} \cos(\theta)]/(kT) = (T_o/T) \cos(\theta)$$

The total interface energy/area is

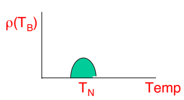
$$F = -J_{Int} \cos(\theta)\, [f^{+} - f^{-}] = -J_{Int} \cos(\theta) \tanh[x]$$

if x is small (viz high Temp.) $\tanh[x] = x - x^3/3$

A comparison of the energy expressions yields $K_1 = -H_E(T_0/T)$ and $K_2 = (H_E/3)\,(T_0/T)^3$ predicting that K_1 and H_E should be comparable and three times larger and in opposite sign to K_2. K_1 and K_2 should also have T^{-1} and T^{-3} dependence.



Introducing a distribution of blocking temperatures

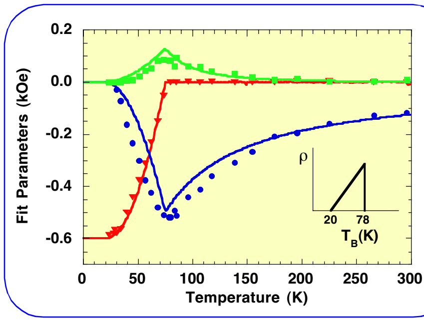


$$H_E(T) = H_E(0)\left[1 - \int_0^T \rho(T_B)\, dT_B\right]$$

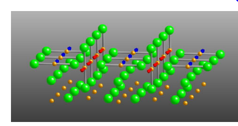
$$K_1(T) = H_E(0)/T \int_0^T T_o\, \rho(T_B)\, dT_B$$

$$K_2(T) = -H_E(0)/(3T^3) \int_0^T T_o^3\, \rho(T_B)\, dT_B$$

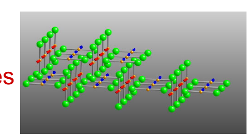
Leads to the fits shown in the next box.



Because the model works so well it is possible to trace the origin of the coupling to the different symmetry of the two AF sublattices



bonds are to nearest neighbours



In summary:
Our experimental results and the model developed to interpret them, provide direct insight into the origin of the exchange bias phenomenon.

Future Directions:
Further tests of the model to guarantee its applicability are needed. Experiments with other F and AF materials must be undertaken. The large anisotropies induced by the AF even above its Neel temperature may have potential applications.

M. Grimsditch, A. Hoffmann, P. Vavassori, H. Shi and D. Lederman, "Exchange-Induced Anisotropies at Ferromagnetic -Antiferromagnetic interfaces above and below the Neel temperature". Phys. Rev. Lett. 90, 257201 (2003).

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